

Off-Grid Renewable Hybrid Power Generation System for a Public Health Centre in Rural Village

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Abstract- The continuous power supply for rural areas can be possible by using renewable hybrid power generation system and also reduction of the energy storage devices for the system. The impact of the shortage of power supply probability, surplus power generation, ratio of the energy supply to load demand, renewable fraction of different types of energy resources (solar and wind) and the combined system components and their performances are analyzed. The technical and economical feasibility of solar PV-Wind hybrid power generation system with battery bank backup is fully discussed. Off-grid PV system, PV-Wind hybrid system is modelled and simulated using HOMER software. The comparative analysis of different possible configurations is analyzed in detail. It is found from the simulation results that the PV-wind hybrid system has the lowest unit cost of energy as compared to independent solar photovoltaic or wind energy system. So, the solar photovoltaic-wind energy hybrid system will be most suitable for the proposed project.

Keywords Renewable energy, Stand-alone system, solar energy, HOMER software.

1. Introduction

Electrical energy plays an important role in the progress path of any developing countries. So, the consumption, utilization and generation of electrical energy should be done in efficient and eco-friendly manner. The expansion of rural electrification in India is very sluggish because of various techno-economic constraints. After 70 years of independence, more than 28,000 villages are not accessed to national grid and particularly in Odisha, 8,750 villages are still to be electrified [1-2].

The State, Odisha is located in between 17.48 N–22.34 N latitudes and 81.27 E–87.29E longitudes. There are approximately 300 sunny days and receives huge amount of solar radiation during one year. The solar energy can be harnessed by using solar cells made of silicon semiconductor devices for rural electrification [3-4]. But the wind energy has equal participation in rural village electrification [5-7]. For the previous few decades, a lot of research works over renewable energy sources has been conducted to signify the techno-economic analysis [8-9] of non-conventional energy applications. The end result shows that the potential of solar

resource or wind resource is much more effective for stand alone or grid connected energy system compared to any renewable sources [10-11] in rural electrifications. Since the outputs of these sources are weather dependent, the individual source is not efficient and also bigger sized for the system. So, the combination of different renewable sources to form the hybrid power system [12-15] is most suitable option.

The hybrid energy system improves the load factor and reduces the replacement and maintenance cost because the renewable resources are complementary to each other. Hybrid power generation system can be installed within short span of time with high reliability and sustainability. The designing and modelling of hybrid power system requires optimum selection of components with efficient control techniques for 24 hour power at an affordable price [16-17].

The optimized configuration of proposed hybrid power generation system should be decided by reducing the cost of energy [18-19]. With specified load demand, the unit sizing and minimum unit cost of energy can be find out by using HOMER software [20]. The optimum sizing with most suitable operating strategies to fulfill the required load demand, the genetic algorithm can be used [21-23]. The

generated excess energy can be stored by the battery bank for short time interval and supply the stored energy during deficit time [24].

This paper brings out vividly about minimizing the energy generated in excess along with reduced unit cost of energy (COE) for the renewable hybrid power generation system. The unit sizing of proposed system configuration and the economical as well as technical properties of the hybrid system elements are also analysed in a thread bare manner in this manuscript. In general, the efficient control policy is planned for the hybrid generation system to synchronize the energy flow amongst various power generators. The simulation is carried out by HOMER software to find out the best possible hybrid model using real time load patterns and weather data.

2. Proposed Model of Hybrid Energy System

The proposed model, off-grid renewable hybrid energy generation system is the combination of photovoltaic panels, wind generators, bi-directional converter (both rectification and inversion purpose) and battery bank (for storage of excess energy) is described in “Fig. 1”. The photovoltaic generator gives power during morning 6 am to evening 6 pm and the wind generator will be operated for 24 hours with variable wind speed. The excess power extracted from both the renewable energy sources (solar and wind) will be stored in the battery bank.

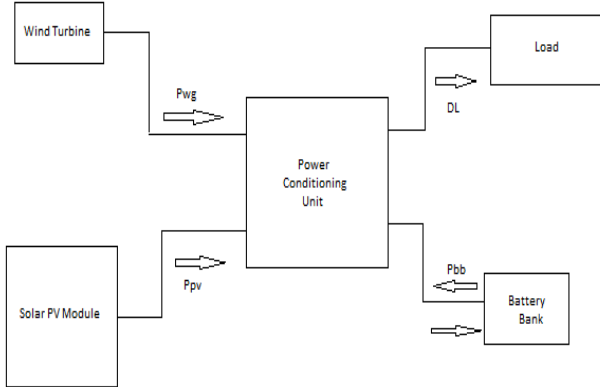


Fig. 1. The proposed model of renewable hybrid power generation system

3. Methodology

There is a small public health centre in the village Gangapada, which is 20 km from Bhubaneswar, capital of Odisha. This village site is taken for the proposed project work due to non availability of grid supply continuously. So, the village people suffer a lot specially the patients. Due to intermittent power supply, it is difficult to preserve the medicines or injections. Therefore for continuous power supply the hybrid energy system comprising of renewable resources (especially solar and wind) can be installed. The important parameters like hourly load demand of that health centre, solar radiation and wind speed of the village is to be

calculated. By the help of HOMER software techno-economic analysis, the most appropriate configuration of hybrid energy system can be selected.

3.1 Modeling and Sizing

There are many constraints which are to be considered while designing the hybrid energy system. These are like the balancing of energy demand and supply, unpredictable renewable energy resources with optimum operating limits. The energy density of single solar PV panel is less than that of single wind generator. For required amount of renewable penetration, the solar panels are to be increased as compared to wind generator until the hybrid system is balanced. The most favorable working policy and the life cycle cost (LCC) of the best practicable model are calculated. The hybrid configuration is to be chosen as the optimized model which is having lowest investment cost, little hour of battery bank autonomy with best service reliability

A mathematical model is prepared for hybrid configuration (PV-wind-battery) and the total capital cost of the system, $T_{cc(sys)}$ is explained by “Eq. (1)”,

$$T_{cc(sys)} = n_{pv} \cdot T_{pv} + n_{wg} \cdot T_{wg} + n_{bb} \cdot T_{bb} \tag{1}$$

where, n_{pv}, n_{wg}, n_{bb} are total no. of solar photovoltaic modules, no. of wind turbines and no. of batteries respectively and T_{pv}, T_{wg}, T_{bb} are the corresponding capital costs.

4. Component Description of Hybrid Power Generation System

The solar PV system, wind generators, bi-directional converters and battery bank are the important components of this proposed hybrid generation system. In this section, the mathematical modeling of each component is discussed.

4.1 Solar Photovoltaic Generator

The formula to calculate the electric energy generated as output of a solar photovoltaic system is given in “Eq. (2)”.

$$P_{pv} = G * A * \eta_{pv} * PR \tag{2}$$

where,

G : Solar radiation on tilted solar modules in (W/m²)

A : Total area of solar module (m²)

η_{pv} : Solar module efficiency (%)

PR : Performance ratio (0.5-0.9)

4.2. Wind Generator

The power extracted from the wind generator (P_{wg}) can be mathematically expressed in “Eq. (3)”, as the function of wind

velocity, rotor swept area, air density and power coefficient of wind turbines.

$$P_{wg} = 0.5 \cdot \eta_{wg} \cdot \eta_{gb} \cdot \rho_{air} \cdot C_p \cdot A_{Rot} \cdot V_w^3 \quad (3)$$

where,

η_{wg} : Efficiency of wind generator

η_{gb} : The efficiency of gearbox or bearings

ρ_{air} : Air density in kg/m³

C_p : Power co-efficient of wind turbine (0.59-0.35)

A_{Rot} : Rotor swept area in m²

V_w : Wind speed in m/sec

where, C_p can be expressed in "Eq. (4)", as function of upstream (V_u) and downstream (V_d) wind speed

$$C_p = 0.5 \left[1 + \left(\frac{V_d}{V_u} \right) \right] \left[1 - \left(\frac{V_d}{V_u} \right)^2 \right] \quad (4)$$

Mathematically, the developed torque in wind turbine generator (T_D) can be formulated in "Eq. (5)", as the function of power extracted from wind turbine and angular speed of wind turbine.

$$T_D = \frac{P_{wg}}{\omega_t} \quad (5)$$

where,

ω_t : Rotor speed of wind generator

4.3. State of charge and discharge of Battery

The power conversion efficiencies in charging and discharging processes are represented by the mathematical model, which are based upon the system energy balance equation. The models are expressed as given in "Eq. (6) & (7)".

$$P_{bb} = (P_{res} - D_L) \eta_{chg} \text{ (where } P_{res} \geq D_L \text{)} \quad (6)$$

$$P_{bb} = \frac{(P_{res} - D_L)}{\eta_{dsg}} \text{ (where } P_{res} \leq D_L \text{)} \quad (7)$$

where,

P_{res} : Total renewable source power

D_L : load demand

η_{chg} : The charging efficiency

η_{dsg} : The discharging efficiency

When both the renewable source (solar and wind) power, is higher than the load demand over a definite period of time, then the surplus power is utilized as charging the battery and the battery bank discharge, if the generated renewable power is higher than the load demand.

The capacity of battery bank (C_{bb}) is in "Eq. (8)" as follows:

$$C_{bb} = \frac{\max \{P_{bb}(t)\}}{DOD} \quad (8)$$

where,

DOD : Depth of discharge of the battery.

The total renewable power available during the operation of hybrid energy system can be explained by using "Eq. (9)", is given below:

$$P_{res}(t) = n_{pv} \cdot P_{pv} + n_{wg} \cdot P_{wg} \quad (9)$$

5. Power Management Strategies

- The mathematical modeling of each component used is discussed for efficient power management by considering the power balance equation of each source with load and battery bank.
- The battery bank is mathematically modeled to take care of overcharging and undercharging.

The most advantageous functional strategy for the hybrid (solar PV-Wind-Battery) combination is computed basing on the hourly operating cost, to lessen the optimal yearly operational cost (C_{opt}) as given in "Eq. (10)".

$$C_{opt} = [8760 \{C_{op(pv)} + C_{op(wg)} + C_{op(bb)}\}] \quad (10)$$

where, $C_{op(pv)}$, $C_{op(wg)}$ and $C_{op(bb)}$ are the operating costs of PV generator, Wind generator and batterybank respectively. The component size, efficiency and properties are used to calculate the operating cost of the proposed hybrid power generation system.

The life cycle cost (LCC) of the hybrid power generation system can be calculated by using both capital cost and operating cost is given in "Eq. (11)".

$$LCC_{(sys)} = (T_{cc(sys)} \cdot CRF + C_{opt}) \quad (11)$$

where, $T_{cc(sys)}$ is the total capital cost of the hybrid system and CRF is the cost recovery factor, as formulated by "Eq. (12)".

$$CRF = \frac{D_r}{\{1 - (1 + D_r)^{-1}\}} \quad (12)$$

where, D_r is the discount on annual rate of interest.

The cost of electricity per unit $\{COE_{(U)}\}$ of hybrid power generation system is calculated according to the equation "Eq. (13)".

$$COE_{(U)} = \frac{LCC_{(sys)}}{D_L} \quad (13)$$

where, D_L is the demanded load for one year (kWh/yr).

The life cycle cost of the optimized configuration of renewable hybrid generation system is as given in "Eq.(14)".

$$LCC_{(sys)} = T_{cc(sys)} + RC + OMC \quad (14)$$

where, RC is the replacement cost and OMC is the operation and maintenance cost of the hybrid system.

6. Renewable Energy Resources and Load Demand

6.1. Solar Radiation

Analyzing the data collected from Metrological Department, Bhubaneswar and of HOMER software, it is found that the average solar radiation of the model village with latitude of 20.183 N and longitude of 85.617 E is about 4.8 kWh/m²/day and yearly mean clearness index of 0.512. “Fig. 2” gives the detail explanation. It is observed from the graphical representation that the solar radiation varies between range of 4.00 kWh/m²/day to 6.18 kWh/m²/day and maximum value in the month of April and minimum in the month of December.

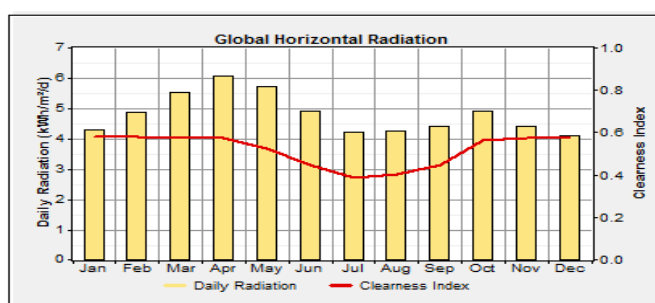


Fig. 2. Monthly average global horizontal solar radiation with average clearness index of case study location

6.2. Wind speed

The wind speed of proposed village is collected from the NASA website. The monthly average wind speed of the site is around 3.91 m/sec. is shown in “Fig. 3”. According to “Fig. 3”, the highest wind speed occurs in the month of April and the lowest speed occurs in the month of January. The most important characteristics of this wind is that there is the stronger speed during summer season and the output of wind turbine will be high to maintain the more electrical energy demand. Around midnight, the wind speed starts decreasing and achieves minimum speed in early morning. The wind curved till it attains the highest speed at afternoon.

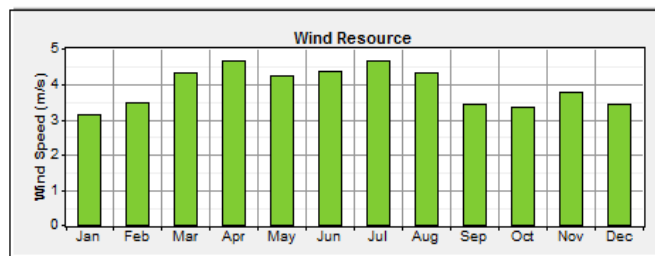


Fig. 3. The average wind speed of the location on monthly basis

6.3. Load Demand

The different types of electrical appliances such as fluorescent lamps, CFL, Fan, refrigerator, color TV and FM

radio sets are connected in small hospital of chosen rural village. Daily electrical energy consumption at hourly interval basis is calculated. The monthly average load profile of the village medical is shown in “Fig. 4”.

The village is electrified by the help of grid supply through a LT line. But the intermittent supply hampers the operational strategy of village health centre. The load demand is an important parameter for the performance analysis of the hybrid power system by HOMER. The energy balance calculations for one year was done by putting the predicted load variation with 1% of day-to-day randomness as well as 1% of time-to-time step randomness. For daily load demand, the load consumption of the village medical had been measured. By the help of HOMER, the daily average electricity was found to be 7 kWh/day with 13 kW peak demand.

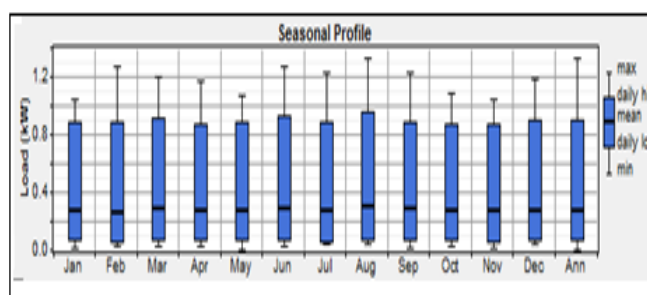


Fig. 4. Monthly load demand of village medical

7. Detailed description of important elements of Hybrid system

The design and simulation of proposed hybrid power generation system was done basing on the availability of solar and wind resources and other weather data. The techno-economic characteristics was given to the HOMER software of different components such as solar PV modules, wind generator and battery bank as energy storing device to find out the best practicable model at reduced cost of energy.

7.1. Solar Photovoltaic Module

The silicon cells are always connected in series and parallel configuration in a module. When the sun rays falls upon the solar panel, the electrical power generates. The solar panel cost is taken as @1.5\$/watt. The input data to HOMER for economic analysis of solar module are given as the capital cost (\$2200), replament cost (\$2100) and operation & maintenance cost (\$20). The life time of the PV modules (20 years), derating factor (80%) and ground reflectance (20%) are taken with two axis tracking system.

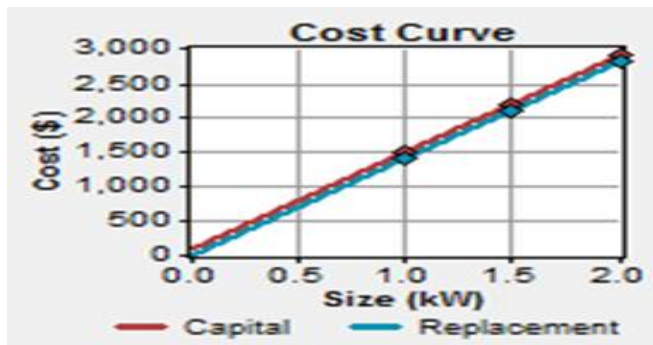


Fig. 5. Cost curve of Solar PV panel

7.2. Wind turbine

1kw DC, wind turbine is chosen for this hybrid system. The electrical output of wind generator depends upon the wind speed which is variable in nature. The power curve indicates (“Fig. 6”) that, the cut-in-speed is 3.9 m/sec and the maximum achieves when the turbine speed is 13m/sec with 24m/sec cut-off-speed. The capital cost, the replacement cost and operation & maintenance cost are considered as \$1200, \$1100 and \$20 respectively in “Fig. 7”. The life time of wind turbine is taken as 20years. The anemometer is placed to measure the wind speed is 25 meters.

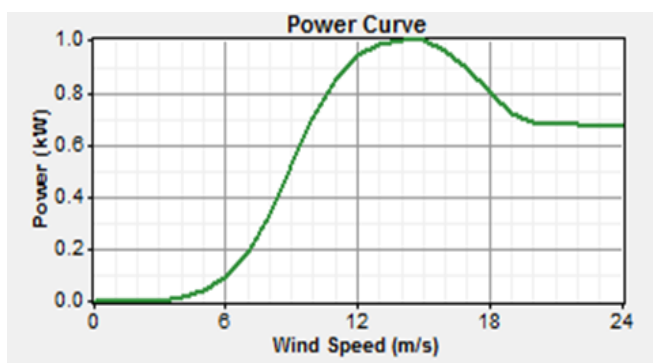


Fig. 6. Expected power curve of wind generator

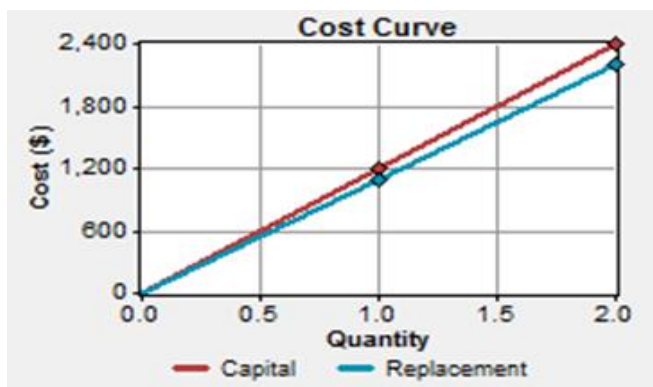


Fig. 7. Cost curve of wind turbine

7.3. Battery

A battery bank is taken in this system as backup source. When the solar PV power and wind power is not sufficient for demand load, the battery bank functions. There are 12

numbers of batteries with 12V; 200Ah and 2.4kWh are connected in this configuration. The cost curve is shown in “Fig. 8”. The capital cost, replacement cost and the operation and maintenance cost are taken \$600, \$500 and \$10 (for each) as input to the software.

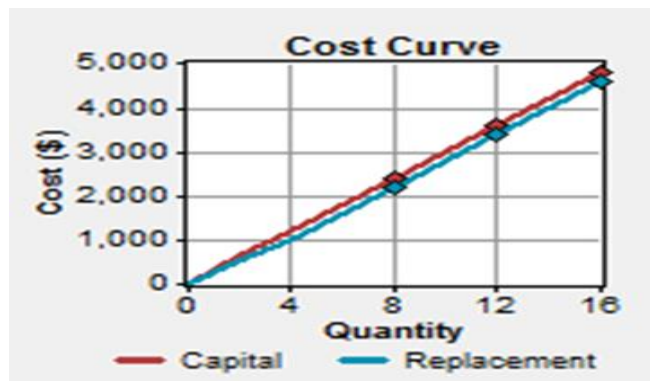


Fig. 8. Cost curve of battery bank

7.4. Bi-Directional Converter

A bi-directional converter is a device which acts as rectifier and inverter simultaneously. It performs the flow of power between DC and AC resources. The installation cost, the replacement cost and the operation & maintenance cost are taken in HOMER for analysis as \$600, \$500 and \$10 respectively. The cost curve of converter is shown in “Fig. 9”. The life expectancy of converter is taken as 15 years and the efficiency of 85% for rectifier and 90% for inverter is given to the software for analysis.

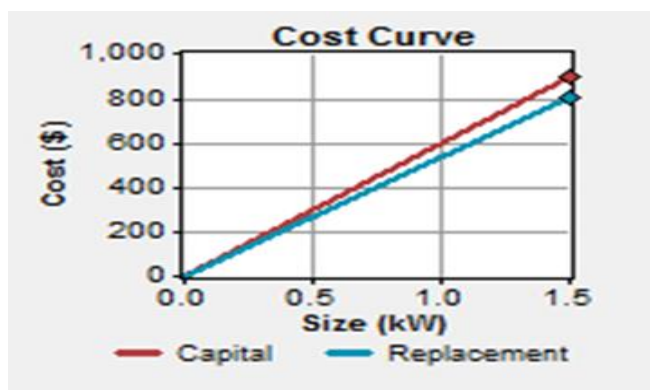


Fig. 9. Cost curve of Converter

8. Design and simulation of hybrid power generation system by HOMER

HOMER (Hybrid Optimization Model for Electric Renewable) [19] is an optimization tool which performs thousands of simulations by using variable renewable/non renewable resources and selects the best achievable configuration for the required systems. The unit sizing and selection of the elements used for hybrid power generation system was done by this software. The various data like hourly load demand with variation of randomness, monthly average

solar radiation with latitude and longitude of particular location, wind speed and the detailed price of individual components used as input parameters for hybrid system. Firstly, it performs the technical assesment of the hybrid system. Then it calculates the net present cost (NPC), operating cost, cost of energy (COE), percentage of renewable fraction used in different possible cofigurations.

A techno-economic study of small village (latitude 20.183 N and longitude 85.617 E) medical was done near Bhubaneswar, Odisha (India). The solar and wind potential of the selected site is sufficient through the year to set up the hybrid power system. The configuration of proposed renewable hybrid power generation system using HOMER software is shown in “Fig. 10”.

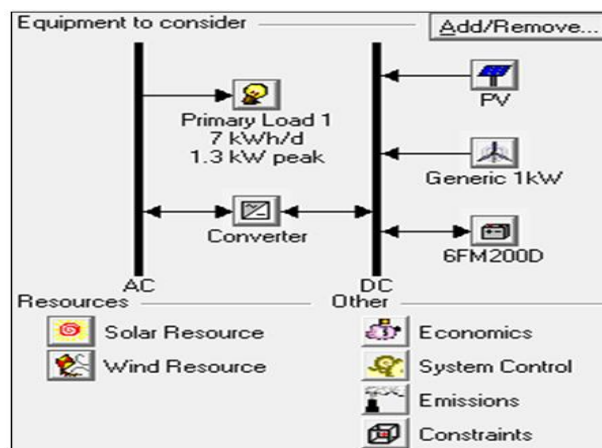


Fig. 10. HOMER simulation model for hybrid system

Table 1. Economical analysis data collected from HOMER software

PV (kW)	WT (nos.)	Battery (nos.)	Conv. (kW)	Capital Cost (\$)	Operational Cost (\$)	Total NPC (\$)	COE (\$/kWh)	Rene.Frac. (%)
1.5	1	12	1.5	7,900	383	12,802	0.392	100
2.0	1	12	1.5	8,600	401	13,726	0.420	100
1.5	2	12	1.5	9,100	433	14,631	0.448	100
1.5	1	16	1.5	9,100	474	15,162	0.464	100
2.0	2	12	1.5	9,800	450	15,555	0.476	100
2.0	1	16	1.5	9,800	492	16,086	0.492	100
1.5	2	16	1.5	10,300	523	16,991	0.520	100

consumption of 7.0 kWh are given as input parameter to the software. The developed model is utilized for simulation,

9. Simulation results and overall discussions

Basing on the required input parameters, a total of 167 simulations were run with high a speed computer. According to HOMER, an optimized PV-wind-battery hybrid power generation system for the village medical which consists of 1.5 kW solar photovoltaic modules (each module of 250 kWp peak), one DC wind generator of 1 kW output power, inverter of 1kW capacity and 12 number of batteries of 12V and 200Ah capacity.

The optimized hybrid power system is having the capital cost of 7,900\$, yearly operating cost of 383\$/yr, the net present cost of 12, 802\$/yr and the unit cost of energy of 0.392\$/kWh with 100% renewable fraction, as shown in Table 1. The output energy and the financial analysis of projected hybrid model with sensitivity analysis are given in subsequent paragraph.

9.1. Optimisation Results

The energy demand of the village medical can be fulfilled by the proposed hybrid (PV-Wind-Battery) model with 100% renewable energy fraction. The monthly average global solar radiation of 4.8 kW/m²/day, the yearly average regional wind speed of 3.91 m/sec at 15 m height and the daily energy

design, performance analysis and optimization of hybrid power generation system. The detailed features of wind energy systems are cut-in-speed (3 m/sec), rated speed (13 m/sec), cut-off speed (25 m/sec), rotor diameter (7 m), hub height (15 m) used in analysis. The solar PV module of 250 Wp at STC of 25°C and 1000W/m² are taken for analysis also. The simulation results of different configurations are given in Table 1.

9.2. Sensitivity Analysis

By this analysis, how the performance of the model changes when the parameters and the design of the model changes is known. It is very useful for decision making, development and further recommendations from the hybrid system. The output of the solar and wind energy depends on the intensity and duration of accessibility of solar radiation and wind speed in the hybrid power generation system. The hybrid design is simulated using sensitivity variables such as global solar radiation, temperature, and wind speed at different heights. Then output such as NPC, COE and RF of hybrid system changed accordingly.

10. Conclusion

An endeavour was prepared to investigate the techno-economic feasibility of hybrid power generation system by utilizing solar and wind resource to decrease the reliance on grid supply to meet up the energy constraint of the village medical located near (18km) Bhubaneswar, Odisha by the proposed PV–wind–battery system. The hybrid system with 100% renewable energy penetration (81% solar and 18% wind) and 1% battery power contribution (12 nos. 12V, 200Ah of each) is selected as the best techno-economically feasible hybrid power system with lowest cost of energy of 0.392US\$/kWh. The battery bank is treated as back up source of energy to the village medical, when the renewable powers will less than the load demand. The life time of proposed project will be for 25 years with little maintenance. It is found from the performance analysis of different configurations that there will be more profit both in terms of technically, financially and environmentally if renewable energy resources are utilized effectively while modelling the hybrid power generation systems.

References

- [1] Central Electricity Authority, Progress Report of Village Electrification. 2014, <http://www.cea.nic.in>
- [2] A. Jain, E. Srinivas, S. Raman, R. R. Gaddam, V. V. S. S. Haritha, & N. S. Venkata, “Sustainable Energy Plan for an Indian Village”, *International conference on Power Technology, IEEE, Hangzhou, China, 24-28 October, 2010*.
- [3] Z. Girma, “Technical and Economic Assessment of Solar PV/diesel Hybrid Power System for Rural School Electrification in Ethiopia”. *International Journal of Renewable Energy Research*, Vol. 3 No. 3, .2013.
- [4] R. A. Bhandari, “Electrification using solar photovoltaic systems in Nepal”, *Applied Energy*, Vol. 88, No. 2, pp. 458-465, 2011.
- [5] G. A. Kamalapur, “Rural electrification in India and feasibility of Photovoltaic Solar Home Systems”, *International Journal of Electrical Power & Amp*, Vol. 33, No. 3, pp. 594-599, 2011.
- [6] A. Chaurey, T. K. Kandpal, “Techno economic comparison of rural electrification based on solar home system and PV micro grid”, *Energy policy*, Vol. 38, pp. 3118–3129, 2010.
- [7] M. Muralikrishn, & V. Lakshminarayan, “Hybrid Solar and Wind Energy Systems for Rural Electrification”, *ARNP Journal of Engineering and Applied Sciences*, Vol. 3, No. 5, pp. 50-58, 2008.
- [8] E. S. Hrayshat, “Techno-economic analysis of autonomous Hybrid photovoltaic-diesel-battery system”, *Journal of energy for sustainable development*, pp. 143-150, 2009.
- [9] P. Nema, R. K. Nema, S. Rangnekar, “A current and future state of art development of hybrid energy system using wind and PV-solar: a review”, *Renewable and Sustainable Energy Review*, Vol. 13, pp. 2096–2103, 2009.
- [10] M. K. Deshmukh, & S. S. Deshmukh, “Modeling of hybrid renewable energy systems”, *Renewable Sustainable Energy Review*, Vol. 12, No. 1, pp. 235-249, 2008.
- [11] B. R. Bagen, “Evaluation of different operating strategies in small stand-alone power system”, *IEEE Transactions on energy conversion*, Vol. 20, No. 3, pp. 654-660, 2005.
- [12] T. Ma, H. Yang, & L. Lu, “Performance evaluation of a stand-alone photovoltaic system on an isolated island in Hong Kong”, *Applied Energy*, Vol. 112, pp. 663–672, 2013.
- [13] M. J. Khan, & M. T. Iqbal, “Pre-feasibility study of stand-alone hybrid systems for applications in Newfoundland”, *Renewable Energy*, Vol. 30, No. 6, pp. 835-854, 2005.
- [14] P. Bajpai, & V. Dash, “Hybrid renewable energy systems for power generation in stand-alone applications: a review”, *Renewable Sustainable Energy Review*, Vol. 16, pp. 2926–2939, 2012.
- [15] A. Asrari, A. Ghasemi, M. H. Javidi, “Economic evaluation of hybrid renewable energy systems for rural electrification in Iran—A case study”, *Renewable and Sustainable Energy Reviews*, Vol. 16, pp. 3123– 3130, 2012.
- [16] A. K. Daud, & M. S. Ismail, “Design of isolated hybrid systems minimizing costs and pollutant emissions”, *Renewable Energy*, Vol. 44, pp. 215–224, 2012.
- [17] A. Kaabeche, M. Belhamel, & R. Ibtouen, “Sizing optimization of grid-independent hybrid photovoltaic/wind power generation system”, *Elsevier, Energy*, Vol. 36, pp. 1214-1222. 2011.
- [18] S. Diaf, G. Notton, M. Belhamel, M. Haddadi, & A. Louche, “Design and technoeconomical optimization for hybrid PV/wind system under various meteorological conditions”, *Applied Energy*, Vol. 85, pp. 968–987, 2008.
- [19] HOMER v 2.84, (National Renewable Energy Laboratory (NREL), USA) Retrieved (2013), from <http://www.nrel.gov/homer>
- [20] R. Posadillo, & R. L. Luque, “Approaches for developing a sizing method for standalone PV systems with variable demand”, *Renewable Energy*, Vol. 33, pp. 1037–1048, 2008.
- [21] A. Al-Karaghoul, L. L. Kazmerski, “Optimization and life-cycle cost of health clinic PV system for a rural area in southern Iraq using HOMER software”, *Solar Energy*, Vol. 84, No.4, pp. 710–714, 2010.
- [22] H. Yang, W. Zhou, L. Lu & Z. Fang, “Optimal sizing method for stand-alone hybrid solar–wind system with LPSP technology by using genetic algorithm”, *Elsevier, Solar Energy*, Vol. 82, pp. 354-368, 2008.
- [23] K. Eftichios, K. Dionissia, P. Antonis, & K. Kostas, “Methodology for optimal sizing of stand-alone photovoltaic/wind generator systems using genetic algorithms”, *Solar Energy*, Vol. 80, pp. 1072-1088, 2006.
- [24] S. Rehman, & L. M. Al-Hadhrani, “Study of a solar PV-diesel-battery hybrid power system for a remotely located population near Rafha, Saudi Arabia”, *Energy*, Vol. 35, pp. 4986–4995, 2010